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Some of the photographs used in this issue are the newly digitized ones from the Film Scanning and Reanalysis Project (page 10). Others were generously donated by Pete Kuran, one of the project's consultants.

COLD WAR FILMS YIELD NEW EFFECTS-DATA FOR U.S. NUCLEAR WEAPONS

Films of the U.S. atmospheric nuclear tests provide breathtaking reminders of the power of nuclear weapons. Now a new project is salvaging and mining these deteriorating films for fresh—and crucial—scientific data about the weapons' yields.

To understand why Lawrence Livermore National Laboratory nuclear weapons physicist Greg Spriggs is spearheading, in partnership with Los Alamos, an urgent search-and-rescue mission to salvage several thousand films documenting U.S. atmospheric testing before they crumble into celluloid dust, you have to appreciate the importance of the information they contain. These deteriorating, often hard-to-find filmstrips and still-photo negatives provide the hard data on key nuclear blast effects that scientists use to determine a weapon's yield.

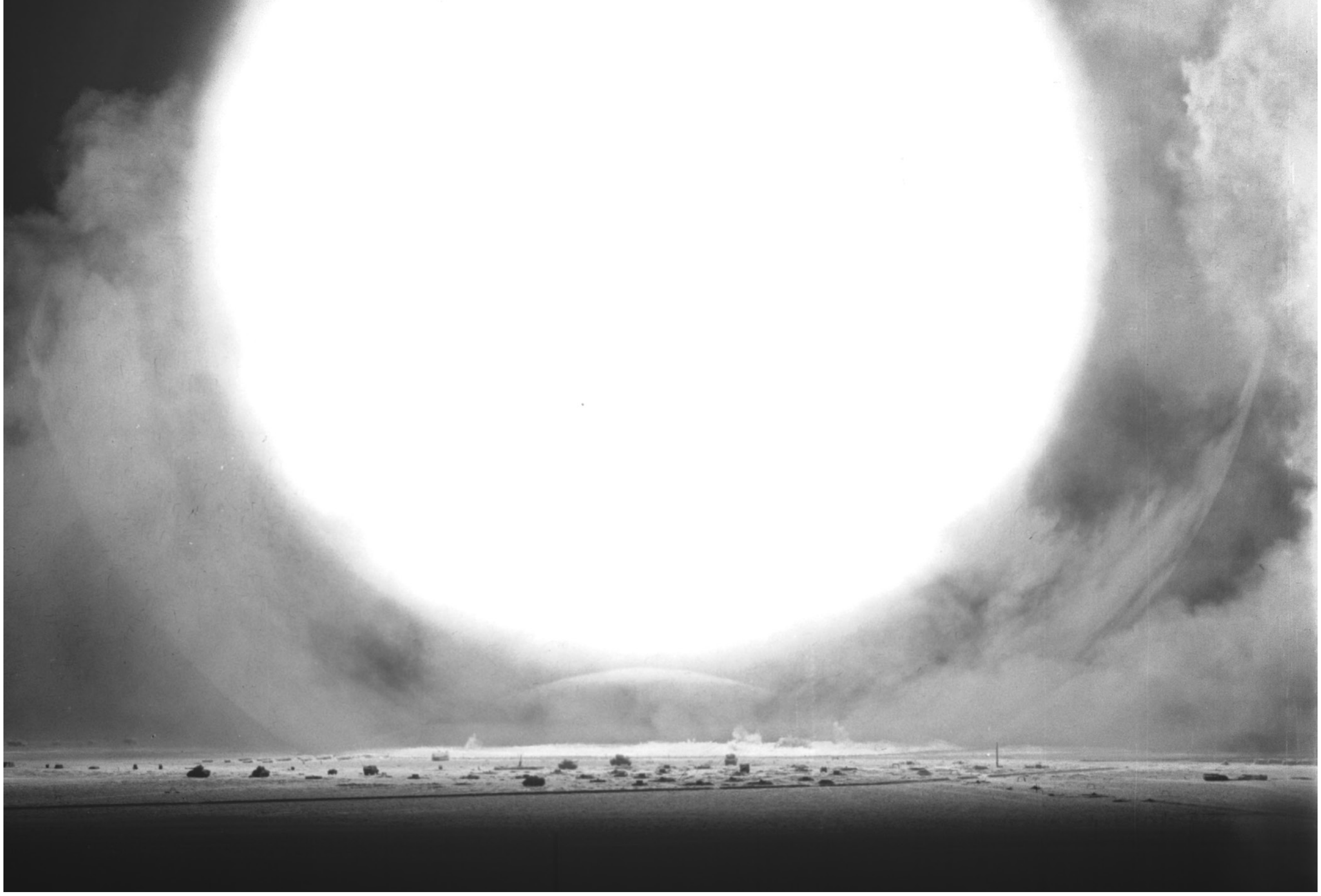
Knowing the yield helps weapons scientists and Department of Defense (DoD) strategists predict whether a given weapon will successfully destroy a specific target. Yield estimates also help forecast the extent of damage an adversary's missile or a terrorist's improvised weapon might cause in the United States or an allied country—knowledge vital to effective planning for mitigation and recovery. Yield, in other words, is the name of the game in both nuclear weapons science and national security. (See "Bigger's Not Always Better," page 9.)

The trouble is, outside of those old films, yield data are very hard to come by.

No New Data

Here's why. Beginning with the Trinity Test in 1945, nuclear explosions lit the skies, churned the seas, and rocked isolated deserts during the U.S. atmospheric nuclear weapon testing program. Scientists filmed every one of the 210 atmospheric tests and manually measured two key effects—thermal radiation (heat and light) and the massive shock wave (the blast)—that had been recorded on film. (The third effect, nuclear radiation, was not recorded on film.) From these, scientists derived crucial, irreplaceable data about the yields of the weapons.

Then in 1963, the Limited Test Ban Treaty ended atmospheric testing—and scientific filming with it. The tests went underground. Finally, when the United States halted all testing in 1992, real-world test data dried up completely.



Test shot Grable was fired from the 11-inch-bore atomic cannon, "Atomic Annie," at the Nevada Test Site (May 25, 1953). The only nuclear cannon shell to be test fired, it weighed 803 pounds and had an estimated yield of 15 kilotons, which exceeded the yield of the 10,000-pound Little Boy bomb that destroyed Hiroshima just eight years earlier. The size of Grable's fireball miniaturizes military trucks and tanks staged near the detonation as targets. The transparent curves in the air beyond both sides of the fireball (lower right and left) are the shock wave. Photographing and then measuring the peak growth of the main shock wave over time provides an estimate of the yield of the weapon. (Photo: Open Source)

Since then, scientists at Los Alamos (and the other nuclear weapons labs) have tested weapons *virtually* by running computer codes on supercomputers (supported by extensive experimental data) to simulate detonations and measure weapon performance. The computer simulations depend on the estimated yields derived from the one-of-a-kind blast-effects data collected from those atmospheric-test films.

Computer simulations of weapons depend on yields estimated from data collected from Cold War atmospheric-test films.

Unfortunately, a few problems cloud these yield estimates. Recently, Spriggs and others realized that scientists were often rushed in analyzing the films, and the techniques used more than 50 years ago produced inconsistent and relatively crude results. Modern techniques, using computers to digitize and analyze the blast effects on the film, can fix those problems.

Unfortunately, to further complicate matters, time is ravaging this film data trove. Film is made from organic material that naturally decomposes over time. Eastman Kodak Company, a major manufacturer of film, estimates that a black and white film has a useful life of about 100 years and color film about half that. With the oldest films now at 70 years and the youngest of the atmospheric test color films already at 53 years, some films are already crumbling into celluloid dust.

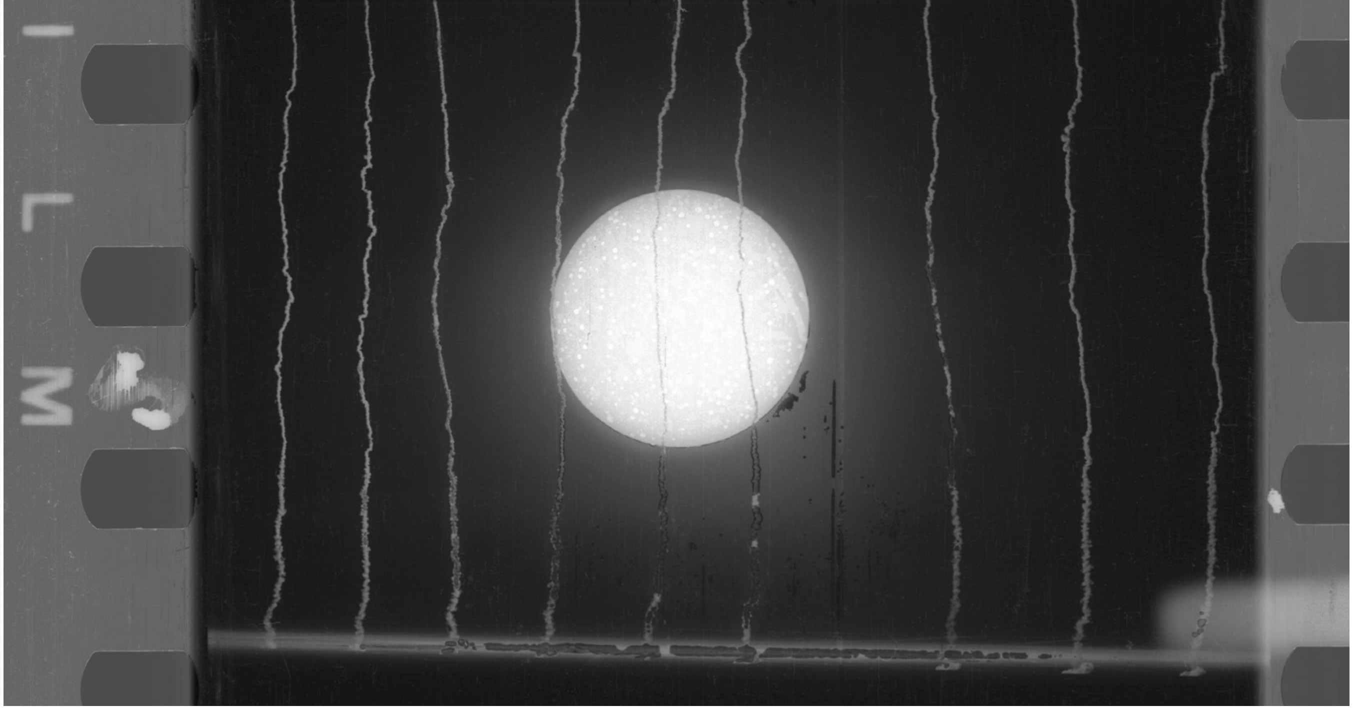
Once these data are gone, they're gone, and there's no place else to get new real-world test data.

Enter Spriggs's Film Scanning and Reanalysis Project, which aims to salvage this visual record and digitally analyze the images, extracting much more reliable yield data than ever before. (See "The Film Scanning and Reanalysis Project," page 10.)

What Films Yield about Yield

Scientists cannot measure nuclear weapon yield directly. They infer it from indirect evidence, such as radiochemical analysis, in which scientists measure the ratios of isotopes (products of the nuclear reactions inside the detonation) that are a function of yield. These isotopes are found in air and soil samples collected after a nuclear explosion. The accuracy of this yield estimate, therefore, depends upon the quantity and quality of the samples.

Some films are already crumbling into celluloid dust.



This photograph of the Climax test (1953) at the Nevada Test Site shows the trails of the smoke rockets that created a grid to help track the speed and size of the shock wave's expansion. These data were then used to estimate the yield of the test: 61 kilotons. (Photo: Open Source)

And there is another way, inferring yield by measuring its effects: the fireball's gigantic pulse of light and heat and the massive shock wave. Working backwards, measuring a weapon's blast effects provides an estimate of its yield as the amount of energy a weapon releases at detonation, expressed as the equivalent in kilotons (thousands of tons) or megatons (millions of tons) of TNT.

But to measure these effects, you first have to pin them down, and a nuclear explosion's effects may last only milliseconds. That's quicker than the blink of an eye, so even if eyewitnesses don't blink, they cannot see them. During the atmospheric tests, the effects were pinned down on film. Using still and motion pictures, in black and white and in color, photographers captured the detonation in its full evolution, the shock wave in its flight, and the thermal radiation of the fireball.

Thermal Radiation: The Double Flash of Light

A double flash of light is the signature of a nuclear explosion, the light's characteristics distinguishing it from anything else. This double flash is really a single flash briefly divided into two when the atmosphere becomes so hot it turns opaque and blocks the light. As the atmosphere cools, the light can escape again, creating the second flash.

The time it takes for this process to run its course depends upon the yield—the bigger the yield, the greater the heat and the longer it takes to see both flashes.

The first flash emerges less than a millisecond after detonation and lasts less than a tenth of a second. Depending on the yield, the second flash can last anywhere from just a few tenths of a second for low-yield detonations to several minutes for high-yield detonations.

The films also provided surprising information about the destructive consequences of the effects.

Using high-speed cameras and films, photographers captured this double-flash phenomenon so analysts could measure it to estimate the yield. (See "The Double Flash Meets the Bhangmeter," page 12.)

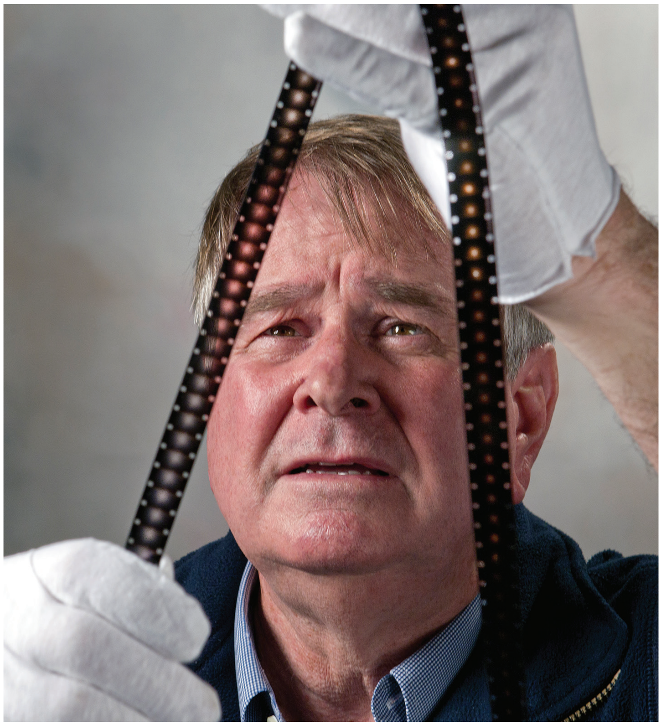
Thermal Radiation: The Fireball

Detonation instantaneously releases the energy from the weapon's nuclear reactions (fission and fusion) and within a millisecond produces what amounts to a small sun, its temperature reaching over 100 million degrees. This is the fireball—a glowing sphere of vaporized weapon debris and superheated air.

The fireball expands, and because it is buoyant (lighter than the relatively cool air around it, like a hot-air balloon), it rises. The amount of energy that created it determines how far it expands, how rapidly it rises, and how long it glows. Like the double flash, these phenomena were captured on film and used to estimate yield.

The Shock Wave

The shock wave's expansion over time also indicates yield. Researchers could photograph the wave's expansion because the dense air compressed at the wave's front refracted the light passing through it. The trails of smoke rockets created a grid that could be photographed to help track the speed and size of the shock wave's expansion.



Lawrence Livermore National Laboratory's Greg Spriggs examines a filmstrip from the Los Alamos National Laboratory archives. (Photo: Open Source)

These test films not only allowed researchers to measure effects, then estimate yields from them, but the films also provided surprising information about the destructive consequences of the effects. For example, shock wave photos revealed critical information that influenced U.S. policymakers during debates in the 1970s and 1980s about where *not* to stage the nation's newest intercontinental ballistic missile, the Peacekeeper, also called the MX missile. (See "The MX Factor," page 14.)

Back to the Past

Los Alamos, Lawrence Livermore National Laboratory, and several Department of Defense organizations are now searching for and retrieving a large portion of the test films from storage as they collaborate on the Film Scanning and Reanalysis Project. Project leader Spriggs is interested in finding the scientific films (approximately 10,000 motion pictures and still photographs), defined as such because professional photographers (with top secret clearances) made them, using unique cameras and films and focusing tightly on the detonations and the effects emanating from them. Another approximately 6,500 films were made as documentaries, covering all the activities that surrounded a test, from preparation to wrap-up. (See "From Glimmer to Fireball: Photographing Nuclear Detonations," page 13.)

As Spriggs finds the films, he uses a high-resolution film scanner to convert them frame-by-frame into digital images. He then analyzes them with sophisticated image-processing software—a far cry from the relatively crude manual analysis techniques of the 1950s and 1960s.

The original analyses were prone to inaccuracies that make today's weapon physicists scratch their heads.

Although Spriggs is only at the mid-point of the work, he has already made some important discoveries. First of all, he has found that the films are indeed rapidly deteriorating; so the project (if adequately funded) is just in time to digitally preserve them.

That Was Then—This is Now

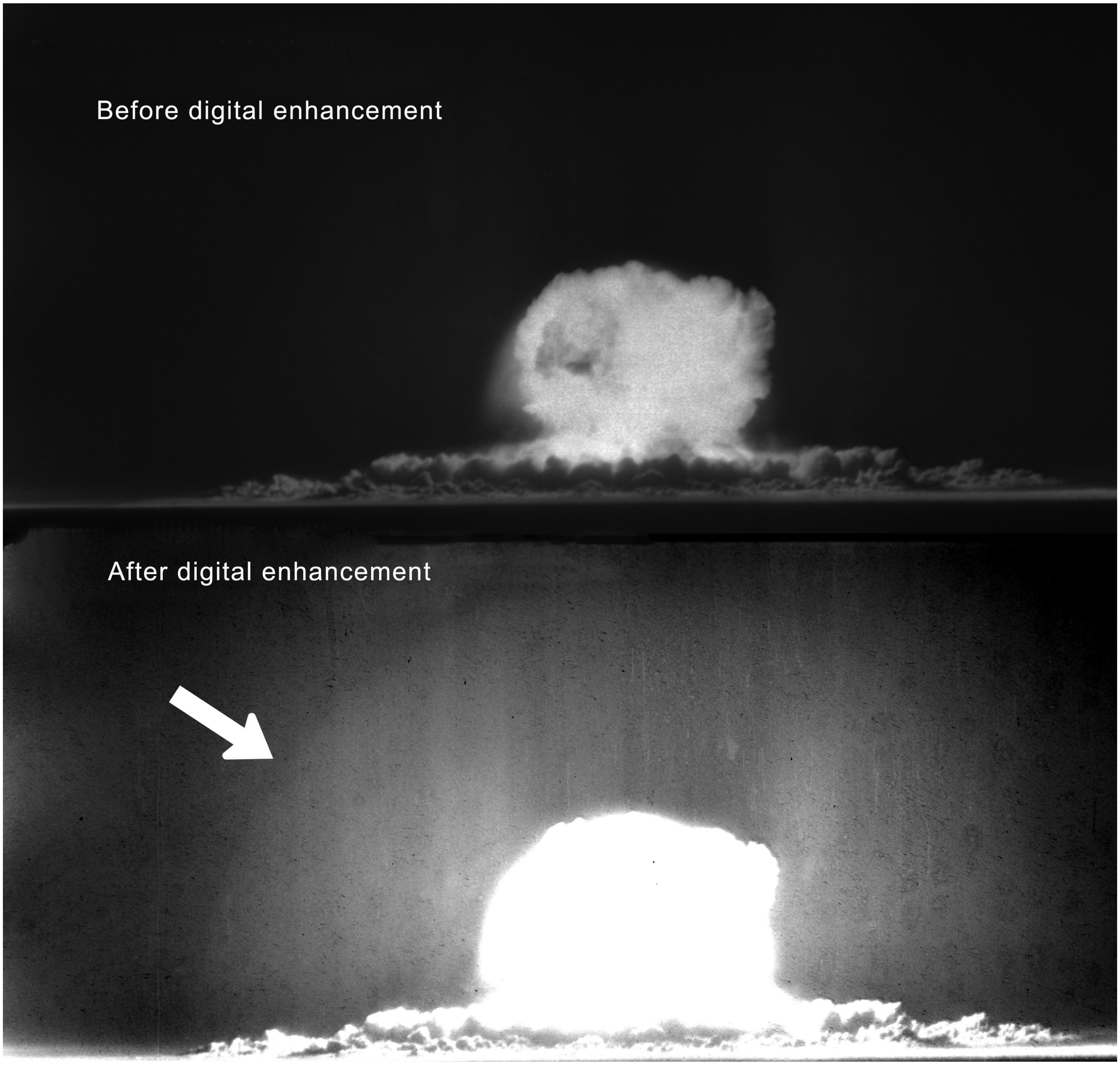
Second and more important, Spriggs has discovered that the original analyses were prone to inaccuracies. The technology of the day prevented more precise estimates of the yields. Measurements were inconsistent and subject to an individual's interpretation and judgment. As such, the results showed relatively large uncertainties and inconsistencies that make today's weapon physicists scratch their heads.

For example, the analysts would place a film of, say, a fireball into a sprocketed, hand-fed system, enlarge it, and project it onto a calibrated grid. Next they would advance the film one frame at a time to measure the size of the fireball as a function of time—the growth rate—looking for what they believed to be the edge of the fireball's peak growth. (These specialized films came with built-in timing marks for this purpose.) One or two people (two would be used to compare each other's results for consistency) would decide where the edge of the fireball stopped on the grid and write those numbers down on an analysis sheet. Then they measured the radius: fireball center to edge.

Spriggs has found these analyses were rushed and incomplete but this means lots of fresh data remains to be mined and analyzed.

This process was slow and had the potential for lots of human error; different people might report different fireball-edge estimates from the same film. Analysts might then calculate two different yields for the same detonation. Sure enough, the yield numbers are sometimes oddly inconsistent across multiple tests of the same weapon design, something that doesn't make scientific sense.

In addition, Spriggs has found these analyses were rushed and incomplete: only a fraction of the films was analyzed.



The digitized image of the Badger test (top) of Operation Upshot-Knothole (1953), Nevada Test Site, has been enhanced (bottom) for a stronger contrast between the shock front (indicated by the arrow) and the sky behind it. Badger was originally estimated to yield 23 kilotons. With the shock wave now clearly visible, the yield can be estimated with far greater precision. (Photo: Open Source)

That's understandable, considering the hectic schedules and stressful deadlines of the Cold War. But this means lots of fresh data remains to be mined and analyzed.

Size Matters

Digitizing these films allows much more rigorous analysis. For example, digital images of the shock wave's position enable researchers to see its terminal edges with finer precision, thus providing higher accuracy in measuring its radius and allowing more exact yield estimates. Based on some preliminary results, Spriggs believes that by digitizing the films he can reduce the uncertainty of some measurements, like those of a fireball radius, from about 20 percent to about 2 percent.

Could a megaton-class weapon actually have an extra five Hiroshima-size yields lurking inside?

Improving the accuracy of this measurement by as little as 1 percent has an outsized impact on the yield estimate. A 1-percent difference in the measured radius of a fireball, for example, would produce a 5-percent difference in the yield estimate. Suppose the original estimate predicted a yield in the 1-megaton range, but the radius measurement was off by 1 percent; that translates to a 5-percent difference in the actual yield estimate, which in this case equals 50 kilotons. The yield of the Little Boy bomb that destroyed Hiroshima was about 10 kilotons. So could that megaton-class weapon actually have an *extra five* Hiroshima-size yields lurking inside?

Spriggs believes he can sharpen the official yield numbers used by DoD strategists and emergency responders.

To Form a More Perfect Number

Because yield numbers are estimates based on inferences, they have inherent margins of error. Spriggs is targeting that uncertainty as he digitizes the test films and gets new, computer-generated measurements from their images. With modern technology, Spriggs believes he can "sharpen" each estimate—bring it as close to perfect as an inference can be—and put a finer point on the official yield numbers used by weapons scientists, DoD strategists, emergency responders, and other stakeholders.

Everything goes back to the yield estimates originally developed during the atmospheric tests.

Everything goes back to yield," he says, "and all the correlations between effects and estimates of yield were originally developed during the atmospheric tests. If we're to more accurately estimate yields and their destructive consequences, and reduce the uncertainties in our weapons codes, we need the best data available. That's what took me back to the films. We need to reanalyze them now that we can, and we need to preserve them so future scientists can analyze them with future technologies."

~Eileen Patterson